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FOR

PHYSICAL LAYERS

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PHYSICAL LAYERS

[0001] This application is related to and claims the benefit of the filing date of provisional U.S. Patent Application Serial No. 60/440,979, filed January 17, 2003.

Field of the Invention

[0002] This invention relates to network computing systems, and particularly to the physical layer of the hierarchy in a network computing system.

Background of the Invention

[0003] It is the nature of the computer system development industry to require an exponential performance advantage over the generations while maintaining or decreasing system costs. In particular, telecommunications and networking computing systems additionally benefit from a reduction in the board size and an increase in system capabilities.

[0004] Computer system processors and peripherals continually benefit from the aforementioned generational performance advantage. This phenomenon is driven by improvements in process technology. In order to realize a proportional system wide improvement in performance, the connection fabric must improve along with the improvements in processors and peripherals.

[0005] A hierarchy of shared buses is a common fabric structure. Levels of performance required for the multiple devices in the system typically differentiate this hierarchy. A given bus is associated with one such level. Bus bridges connect the buses. In this structure a low performance device does not burden a high performance device.

[0006] This type of structure benefits from an increase in bus frequency, a wider interface, pipelined transactions and out of order completion capability. However,

these techniques are well known, and are exploited to their full potential. Further increases in bus width will reduce maximum bus frequency due to skew effects i.e. as the data-path is altered to include a greater number of data bits, the skew, between those individual bits, originating in the transmission medium, becomes increasingly severe. A wider bus will also increase pin count. This will affect cost, and limit the interfaces on a device.

[0007] Furthermore, the maximization of bus frequency and width is incompatible with a many-device connection. Finally, it would be advantageous to increase the number of devices capable of direct communication.

[0008] Therefore, point to point, packet switched, fabric architectures have emerged as an alternative to the aforementioned bus structures. Such an architecture is beneficial in network equipment, storage subsystems and computing platforms. Networks of this architecture transmit encapsulated address, control and data packets from the source ports across a series of routing switches or gateways to addressed destinations. The switches and gateways of the switching fabric are capable of determining from the address and control contents of a packet, what activities must be performed. The architecture is capable of providing an interface for processors, memory modules and memory mapped I/O devices.

[0009] In a typical packet switched interconnect, the functionality is organized into a hierarchy of multiple layers. The disposition of typical layers apportions the functions most related to control and compatibility to the highest layers. The most rudimentary and device oriented considerations are apportioned to the lowest layer. The physical layer is the lowest or most physically fundamental layer.

[0010] Physical layer specifications define the interface between devices including packet transport mechanisms, flow control, and electrical characteristics.

[0011] For a packet switching network to be highly efficient, the physical layer of the network must strive to meet certain criteria, and for functions of the physical layer to be efficiently carried out.

[0012] Specifically:

[0013] The transmitter and receiver must establish the data integrity of the channel, and ideally should do so without additional hardware or cumbersome handshaking.

[0014] The physical layer should incorporate boundary scan testing in a manner that does not unnecessarily skew time sensitive signals i.e. clocks.

[0015] Should the physical layer incorporate delay lines, no significant jitter should be introduced due to variances in the manufacturing process.

[0016] Should the network define words that are multiple bytes in length, any corresponding word or byte frame signals, ideally do not require handshaking or additional pin count for synchronization.

[0017] Should a physical layer receive clock incorporate multiple delay lock loops (DLLs) for synchronizing with a transmit clock, it should be possible to allow adjustments of a fraction of the finest delay lock loop.

[0018] The problem with addressing these issues with 0.13 μ m CMOS is that the power supply voltage is 1.2V and this creates a real problem for the non logic designer as most of the techniques used in 3.3V or even 2.5V such as cascoding current sources (to improve output impedance and gain of circuits) either do not work well (or do not work at all).

[0019] In many kinds of circuits, there is a fundamental set of contradictory requirements: high speed operation, rail to rail inputs and or outputs, and low voltage

operation. Some examples of these are: DLLs, PLLs, charge pumps, op amps, IO pads. In all these cases, the biasing is done with current sources and circuit performance is often limited by these current sources.

[0020] There is a need for improvements in the physical layer of a packet switched fabric, to address these concerns, in order to ensure that the fabric is highly efficient. In particular there is a need for increased co-ordination and synchronization between transmission and reception interfaces while maintaining a minimum increase in pin count, clock skew, and cycle overhead.

[0021] In particular, at 0.13um, the power supply voltage is 1.2 V. This presents a real problem for a designer of circuits that are not logic circuits because typical techniques used in 3.3 V or even 2.5 V domains either do not work well or do not work at all. For example cascading current sources to improve output impedance and gain circuits. Part of the problem is that in many kinds of circuits there are fundamentally contradictory requirements, such as high speed operation, rail-to-rail inputs and/or outputs, and low voltage operation. For example, these circuits include delay lock loops (DLL), phase lock loops (PLL), charge pumps, operational amplifiers (Op Amps), input/output (I/O) pads.

Summary of the Invention

[0022] This invention addresses the need for improvement in the physical layer of a packet switched fabric communication system such that the fabric is highly efficient. A packet switched fabric communication system has a switch, communications medium and a number of end points. The switch and end points incorporate ports. In network hierarchy, the physical layer is responsible for packet delivery; Improvements to operation of ports falls within improvements to the physical layer.

[0023] The improvements can be better understood by enumerating the advantages and embodiments:

[0024] It is an advantage of the present invention to overcome the need for handshaking or additional pin counts used in testing the transmission data integrity of a bus. This first advantage derives from an apparatus for testing the integrity of a data message. This apparatus is an alternative to a handshaking routine or the use of a circuit that employs dedicated bus signals.

[0025] In a high-speed data bus system, maximum performance requires the skew of each bit of the data line to be adjusted to optimize the moment of the transmission cycle in which data sampling occurs. In order to achieve this optimization, the bus is 'trained'. As a pre-amble to operation, the delay associated with each line is varied and tested iteratively until the best possible delay is found. It is necessary to test the performance of this high-speed bus and identify errors.

[0026] In a corresponding embodiment, a physical layer is disclosed including: a transmitter incorporating one pseudo-random bit-stream generator for generating test vectors, a receiver incorporating a second pseudo-random bit-stream generator and a comparator; where the receiver uses the comparator to compare received test vectors to locally generated test vectors.

[0027] It is an advantage of the present invention to incorporate a test circuit that does not introduce further skew into critical clock signals. In the art, boundary scan signals are multiplexed with system signals in order to test integrated devices. However direct incorporation of scan signals into a clock multiplexed node may unnecessarily load the clock, creating a skew.

[0028] In a corresponding embodiment a multiplexing circuit is disclosed having: two tiers multiplexing, the first tier multiplexing a boundary scan signal with a set of clock grouped signals, the second tier selecting a first tier output on the basis of the clock.

[0029] It is an advantage of the present invention to incorporate DLL delay lines in the physical layer, while introducing no significant jitter due to variances in the

manufacturing process. Manufacturing variances between n and p type transistors may cause unbalanced pullup and pulldown behavior in a bias circuit that ultimately results in DLL jitter.

[0030] We introduce a device to adjust the current as a function of process, voltage and temperature. The device is a current bleeder.

[0031] In a corresponding embodiment a physical layer segment is disclosed including a delay line generator comprising: a voltage control input, independent positive and negative bias generators with dedicated positive and negative bandgap references, wherein each of the generators is complementarily responsive to variances in the properties of internal n and p type transistors.

[0032] The nature of the improvements involves superior co-ordination, synchronization while maintaining a minimum increase in pin count, clock skew, and cycle overhead.

Brief Description of the Drawings

- [0033]** Fig. 1 is a block diagram of a system of the prior art.
- [0034]** Fig. 2 is a block diagram of a system of the prior art.
- [0035]** Fig. 3 is a block diagram of an endpoint of the prior art.
- [0036]** Fig. 4 is a block diagram of a network hierarchy of the prior art.
- [0037]** Fig. 5 is a block diagram of a handshaking system of the prior art.
- [0038]** Fig. 6 is a timing diagram of a handshaking system of the prior art.
- [0039]** Fig. 7 is a block diagram of a co-ordination system.
- [0040]** Fig. 8 is a block diagram of a transmitter.
- [0041]** Fig. 9 is a block diagram of a Pseudo Random Bit Stream Generator.
- [0042]** Fig. 10 is a block diagram of a receiver.
- [0043]** Fig. 11 is a multiplexing circuit according to the prior art.
- [0044]** Fig. 12 is a multiplexing circuit.
- [0045]** Fig. 13 is a block diagram of a DLL of the prior art.

- [0046] Fig. 14 is a diagram of bias circuits and delay lines according to the prior art.
- [0047] Fig. 15 is a block diagram of a DLL.
- [0048] Fig. 16 is a diagram of bias circuits and delay.
- [0049] Fig. 17 illustrates the current bleeder device of Fig. 16; and
- [0050] Fig. 18 illustrates an implementation of the circuit of Figs. 16 and 17.

Detailed Description of the Preferred Embodiment

[0051] Referring to Fig. 1, 2 there is illustrated, in a block diagram, a packet based switching system of the prior art. The switching system **10**, includes a switch fabric **12** and end points **14a-14d**, connected to the fabric **12** by channels **16a-16d**. The fabric core **20** is connected to the channels **16a-16d** by ports **18a-18d**. The end points are connected to the channels by ports **22a-22d**. Note that although 4 ports are shown, the number of ports is not fixed. A regional view of the fabric **12** includes the fabric core **20** and the ports **18a-18d**.

[0052] Figure 3 shows greater detail of a single endpoint **14a** and the respective portion of the fabric **12**. The end point **14a** is connected to the fabric **12** via channel **16a**. Both the fabric and endpoint contain ports **18a** and **14a**, respectively, for coupling to the channel **16a**. The channel **16a** is a duplex channel containing an upstream channel **30** and a downstream channel **28**. The port **22a** contains transmitter **24** and receiver **26** for cooperating with the upstream channel **30** and downstream channel **28**, respectively.

[0053] The operation of a network communication system over such a switching system **10** is accomplished through the specification of a network hierarchy. Referring to figure 4 there is such a network hierarchy **50** consisting of a number of specification layers **52**. Although 4 or more layers are shown there is no limitation on the number of layers. Conventionally, in such a specification the lower most, or most physical, layers define the device interfaces, packet transport mechanisms, flow control and electrical characteristics. The higher layers will define addressing, transaction protocol, and interface with the communication system. Throughout the

remainder of the disclosure we refer to the lowest layer **54** as the physical layer. Further the operation of the ports **14a-14d**, **18a-18d**, transmitters **24**, and receivers **26** are specified in this convention by the physical layer **54**.

[0054] One aspect of the physical layer is the co-ordination of transmission and reception. Typical prior art co-ordination involves handshaking. Referring to the block diagram of figure 5 is a handshaking system **100** including a channel under test **130**, similar to channels **28,30**, and corresponding test apparatus including the transmitter **120**, the receiver **140**, and a back channel **150**. The back channel **150** may be dedicated, or may be the return data channel of an associated duplex system.

[0055] Referring to the timing diagram in figure 6: A set of test vectors **160** is asserted on the test channel **130**. The receiver retransmits reply test vectors **170** on the back channel **150**. Finally the transmitter returns an error count **180** on the test channel. It is obvious that the error count **180**, ideally, be transmitted on the test channel in such conditions conducive to correct transmission (e.g. lower frequency, high redundancy) rather than the conditions that are being tested. As an alternative, a dedicated channel may exist for this purpose. Similar considerations apply to the reply test vectors **170**, if the back channel is the complementary channel of a duplex system.

[0056] In the inventive alternative, first, referring to figures 7 and 8, we have a segment of the physical layer, a co-ordination system **210**, comprising a transmitter **220**, a channel under test **230**, and a receiver **240**. The transmitter **220** incorporates a multiplexer **250**, the output of which is coupled to the channel under test **230**. The transmitter also includes a pseudo-random binary sequence (PRBS) generator, **260**. PRBS generator **260** is output coupled to multiplexer **250** input by composite test vector data output **270**. The multiplexer also incorporates the input **280** of the transmitter **220**. A test vector control line **290** is coupled to the control of the multiplexer **250** and to an input of the PRBS generator **260**.

[0057] Referring to figure 9, the PRBS generator **260** includes 32 shift registers **300** coupled in series. Each shift register, **300**, is coupled to a one bit output **270(n)** of

a series of outputs **270(0..31)** forming the composite test vector data output **270**. The generator employs exclusive-or circuits, **320**, **325**, and **330**, input coupled to the 2nd, 3rd, 5th and 16th bits of test data output **270**. The output of these circuits is a seed **310** coupled to the first input of the series of registers **300**. The shift registers **300** are all coupled to a common clock **305** and a common reset **315**. Control line **290** is a logical precursor of the clock **305** and reset **315**.

[0058] In operation, referring back to figure 8, the PRBS generator **260** PRBS generates test vector data (a pseudo-random sequence of test vectors 65,356 elements long, with longest runs of consecutive 1s or 0s over 2000) to be output on output **270**. Such a level of randomness is sufficient to identify datapath errors. A test control signal, exerted on test vector control line **290** allows the multiplexor **250** to choose between data on input **280** or the test vector data. Further this control on line **290** may serve to signal the beginning of the pseudo random sequence. Those skilled in the art will understand circuits capable of coordinating this input **290** and the shift register reset **315**.

[0059] Referring to figure 10 we have a detailed expansion of receiver **240**. The receiver **240** incorporates a receiver output line **335** coupled to the channel **230**. The receiver **240** also incorporates a PRBS generator **340** identical to the PRBS generator in the transmitter **260**. A bitwise XOR circuit **345** is input coupled to the generator **340** output and to the channel **230**. The outputs of this circuit **345** are combined in OR circuit **350**. The output of this, in turn, is coupled to the enable of counter **355**. The counter is coupled to an error count line **360**. The outputs of circuit **350** are also connected to the trigger **365**. This trigger is coupled to the generator **340**, to the reset of counter **355**, and to a second counter **370** at the reset and at the enable (inverted). The output of the second counter **370** is coupled to the total count line **375**. Both counters are coupled to a receiver clock **380**.

[0060] In operation the generator **340** is held in a reset condition producing the first series vector. The vector output of the generator **340** undergoes a bitwise comparison with the incoming received data. When the initial vector is detected at the

comparator 345 and 350, the trigger 365 releases the reset on the generator 340 and counters 355, 370 allowing the generator to produce the entire series for comparison, and allowing the counters to count the matches versus the total count.

[0061] Another aspect of the invention is an apparatus to incorporate a boundary scan test circuit into the physical layer while minimizing the amount by which this circuit reduces the performance of the transmitter or receiver. A boundary scan test circuit is used to isolate an integrated circuit (for applying test vectors to this circuit) or to isolate circuit board connections (to test the integrity of these connections).

[0062] In a multiple data rate bus system, there is a need to multiplex several data together for assertion on the bus, such assertion being controlled by the clock. There is also a need to include in the multiplexer, test data, if a boundary scan device is included. There is a need for a circuit that multiplexes all these signals, while maintaining the clock latency equivalent to a circuit without the boundary scan.

[0063] Another aspect of the physical layer is the incorporation of boundary scan testing. Referring to figure 11, a prior art multiplexing circuit 401 is shown. It includes a selection multiplexer 422. This multiplexer 422 is coupled to the selection control line 498 and to the output 494 of the circuit 401. The inputs of the multiplexer are connected to a set 460 of non-test datums 440 and one test datum 430.

[0064] In operation the control line 498 selects one of the various data on the various data lines 460 and 430. This data may, for example, correspond to one boundary scan datum and many data to be asserted in non-test operations, but at different portions of the clock cycle. In this instance line 498 carries a composite test mode select / clock signal. This composition of the clock can generate unnecessary complications on a critical signal path.

[0065] In a second embodiment of the invention, referring to figure 12, a multiplexing circuit 400 is shown. It includes two multiplexing stages: an enabling stage 410, and a selection stage 420. The enabling stage 410 is a bank of single bit

multiplexers each coupled to the test data line **430** and a single non-test datum line **460**. The set of non-test datum lines are collectively the non-test data set bus **440**. The test mode select line **480** is the multiplexing control coupled to enabling stage **410**. Each multiplexor of the enabling stage **410** is output coupled to an intermediate datum line **470**. The intermediate datum lines form an intermediate data set **490**. This set **490** is coupled to the inputs of the selection stage **420**. The output of the selection stage is the multiplexer output **494**. The selection stage also is coupled to the selection control line **496**.

[0066] In operation this multiplexer individually multiplexes the test data on the test line **430** with each datum line **460** according to the test mode line **480**. The resultant multiplexed signals (asserted on intermediate lines **470**) are again multiplexed according to the selection control line **496**. This arrangement unburdens control line **496** from overhead. This consideration is critical if line **496** is a clock.

[0067] It can be understood from this description that the test and non-test data are multiplexed in a manner adding no additional latency to the select signal (or clock), than would exist in a simple circuit that multiplexed only non-test data.

[0068] A third aspect of the invention is an improvement in the generation of bias voltage for a Voltage-Controlled Delay Line (VCDL). A VCDL is a building block of a Delay-Lock Loop (DLL). The DLL, in turn is a circuit widely used in clock deskewing, clock frequency synthesis, and high-bandwidth interfaces in the physical layer.

[0069] A prime design concern in the development of DLLs is the reduction of time-varying offsets in the output clock phase. This phenomenon is referred to as jitter. In one particular contribution to jitter, process variation between n and p type transistors, leads to variation in rise and fall times in the voltage control input of the VCDL. This will have a direct impact on the output phase. The object of this embodiment is to reduce or eliminate the process dependence in both the pull-up and

pull-down bias of the voltage control. Further, this object is met without resorting to large capacitors, that would have an adverse effect on the footprint of this circuit.

[0070] Referring to figure 13 there is a block level arrangement of a known DLL **560**. The Delay line **565** is the output of a bias generator **570**. The line **565** is fed back to a phase comparator **575**. The phase comparator is output coupled to a charge pump **580**, in turn coupled to the bias generator **570**. The bias generator is also coupled to a bandgap reference **590** as an input.

[0071] In figure 14, two prior art voltage control bias circuits and VCDLs are shown. In the first of these circuits **500**, delay lines consist of a positive bias line **554** and a negative bias line **552**. The positive bias line **554** is coupled to a current mirror consisting of transistors **512** & **514**. The negative bias line **552** is coupled to a current mirror consisting of a transistor **520**. Transistor **512** is coupled via a resistor **516** to a voltage to current converter **526** formed of a transistor **518** and resistor **522**. The circuit is biased by a lower voltage **524** coupled to resistor **522** and transistor **520** and a higher voltage coupled to the transistors **512** and **514**. The input voltage **550** is coupled to transistor **518**. The purpose of resistor **516** is to limit the maximum frequency of operation. Phase offset information is asserted as the charge pump voltage onto the input **550**.

[0072] As an alternative to circuit **500**, circuit **502** consists of a positive bias line **554** and a negative bias line **552**. The negative bias line **552** is coupled to a current mirror consisting of transistors **528** & **530**. The positive bias line **554** is coupled to a current mirror consisting of a transistor **536**. Transistor **528** is coupled via a resistor **532** to a voltage to current converter **540** formed of a transistor **534** and resistor **538**. The circuit is biased by a lower voltage **524** coupled to the transistors **528** and **530** and a higher voltage coupled to resistor **538** and transistor **536**. The input voltage **550** is coupled to transistor **534**. The purpose of resistor **532** is to limit the maximum frequency of operation. Phase offset information is asserted as the charge pump voltage onto the input **550**. The difficulty with both the prior art bias circuits is a

vulnerability to process mismatch distorting the response of the delay line. This contributes to jitter.

[0073] Referring to figure 15, there is illustrated a bias circuit in accordance with a third embodiment. Bias circuit consists of two subcircuits a positive bias circuit, 600, and a negative bias circuit, 610. These circuits are biased by Vdd, 620, and Vss, 630. Temperature dependant voltage compensation is provided via the bandgap bias signals 640, 650, 660, and, 670. Phase offset information is asserted as the charge pump voltage, 680. The positive bias and negative bias circuits output is coupled, respectively, to a positive bias line, 690, and to a negative bias, 700 for the VCDL. The bias voltages of these lines are used to supply the delay element(s) of the VCDL in a manner similar to bias lines 552 and 554 of the prior art.

[0074] Referring to figure 16, the negative bias circuit, 610, is detailed. Negative bias circuit, 610, consists of the main bias P channel device, 710. It is referenced to Vdd, 620, and its gate driven by the bandgap bias signal VBGP, 660. A weak bleeder N device, 528, referenced to Vss, 630, and its gate driven by the bandgap bias signal VBGN, 670. Also included is a current control device, 730, which provides current sweeping capability and as a result delay control of the VCDL. This device is also referenced to Vdd, 620, and is controlled by the charge pump voltage, 680. Under nominal conditions main bias P device, 710, provides most of the current to the positive bias circuit, 600, with the weak bleeder N device, 528, bleeding off excess current. When P doping is strong and N doping is weak, more current is provided by the P main bias device, 710, and less is subtracted by a weak bleeder N device, 720, resulting in larger current delivered to a biasing N current mirror. The opposite happens in the case of weak P doping, strong N doping. Less current is provided by the main bias P channel device, 710 and more current is subtracted by weak bleeder N device, 528, resulting in less then nominal amount of current delivered to the biasing N current mirror.

[0075] More specifically, a bleeder circuit is added to adjust the current as a function of process, voltage and temperature. The bleeder is sized with a minimum

gate length and many short stripes and biased so that it does not draw much current at a slow (SS, hot, low temperature) corner, but draws more current at a fast (ff, cold, high temperature) corner. Since the bleeder circuit's current is subtracted from the current that goes to the delay cell, the bleeder circuit reduces the variation of the delay cell as a function of process, voltage and temperature (PVT).

[0076] The Positive bias circuit, 600, is the complement of the negative bias circuit, 610, with respect to doping and reference biasing and is used to positively bias the VCDL. Referring to Fig. 17, the operation of the bleeder device of Fig. 16 is explained in further detail.

[0077] The bleeder of device 528 is sized (with minimum gate length and many short stripes) and biased so that it does not draw much current at slow (ss, hot, low voltage) corner, but draws more current at the fast corner (ff, cold, high temp). Since this current is subtracted from the current that goes to the delay cell 800, it reduces the variation of the delay cell verses PVT (a similar circuit using PMOS devices is used for the P bias). Notice also that this has the added benefit of adjusting for the odd process corners when the P and N devices do not track i.e. strong N, weak P and vice versa since they are adjusted independently.

[0078] The circuit behavior can be adjusted by both the sizing and the characteristics of Vgate. This means one can tune these two variables independently to minimize the overall circuit variation. The choice of minimum gate length and many short stripes for the bleeder device 528 is used to accentuate the variation in the characteristics of the bleeder device with process and improve its effectiveness for compensation.

[0079] While the bleeder device is shown for use with a delay cell, it will be appreciated that the bleeder device can be used with delay lock loops (DLL), phase lock loop (PLL), charge pumps, op amps, and I/O pads.

[0080] Referring to Fig. 18, there is illustrated in a simplified schematic, an implementation of the bleeder device 528 for both positive and negative bias. By using a band gap, the circuit of Fig. 18 provides PTAT current, that to a first order helps to reduce template dependence of the current. The Vgate nodes are provided by resistors; which give a desirable instant voltage regardless of MOS processes.

[0081] Similarly, a bleeder circuit using PMOS devices is used for P bias. This also has an added benefit of adjusting for odd process corners when P and N devices do not track one another (e.g., strong N, weak P and vice versa) since they are adjusted separately.

[0082] It may be understood by those skilled in the art that variations may be made to these implementations while still implementing the essential inventive concept.